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M.V. ARCTIC
Structural Performance

Summary Report

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MV ARCTIC STRUCTURAL PERFORMANCE

SUMMARY REPORT

TP 5681E

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FEBRUARY 1985

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17. Abstract

Analysis of the structural response data collected onboard the MV ARCTIC during the 1979-81 operating seasons is reported.

The project was conducted in two phases, the first being identification of quality data and development of analysis procedure; and the second, reduction of the bulk of the data.

Worst loads were experienced while operating in up to 10/10th ice with multiyear floes present, being three to four times those experienced when operating in level ice. The large number of gauges permitted stress contours to be developed for each ship/ice interaction scenario, indicating areas of peak loading and their extent. Several cases of damage were also analyzed and loads up to 23 MN (2340 tonnes) estimated as the cause. Analysis of measured stress in relation to Canadian Arctic Shipping Pollution Prevention Regulations indicated that plates are subject to a high probability of permanent damage, while main frames appear to have an adequate safety margin.

It is considered that the data collected, when combined with other technology in the field, has contributed to an understanding of the structural response of the vessel in ice and identified areas for future improvement.

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17. Résumé

Ce rapport concerne l'analyse des données amassées à bord de l'ARCTIC, durant les saisons de navigation de 1979 à 1981. Le programme de recherche s'est déroulé en deux étapes. La première a permis d'apprécier la qualité des données et de mettre au point des méthodes d'analyse; la deuxième, de réduire ces données.

Les charges les plus sévères ont été constatées à l'égard d'une couverture de glace 10/10 constituée en partie de floes de plusieurs années; les niveaux enregistrés étant de trois à quatre fois supérieurs à ceux d'une marche continue dans une glace uniforme. Le nombre élevé de capteurs a permis de tracer des courbes d'isocontrainte à l'égard de diverses combinaisons d'interaction coque-glaces, et où sont mises en évidence les zones soumises à des charges maximums ainsi que l'amplitude de ces charges. Plusieurs cas de déformation permanente ont été analysés, attribuables à des charges de l'ordre de 23 MN (2340 tonnes). La comparaison des valeurs de contrainte mesurées avec les valeurs de résistance stipulées dans la Loi sur la prévention de la pollution des eaux arctiques a montré que les risques de déformation permanente des plaques de bordé sont élevés, alors que les membrures semblent bénéficier d'une marge de sécurité suffisante. Une appréciation de la chaîne de mesure a été faite, complétée de suggestions sur la mise au point des techniques envisagées pour l'avenir.

Le rapport conclut que l'ensemble des observations, ajoutées aux connaissances déjà acquises dans le domaine considéré, auront contribué à une meilleure compréhension des phénomènes en jeu et à l'identification des secteurs où des perfectionnements sont possibles.

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FOREWORD

The MV ARCTIC - a Class 2 icebreaking ore carrier was fitted with an onboard data acquisition system which collected structural response data during voyages into the Canadian Arctic in 1979 through 1981.

This data has been catalogued, reduced and analyzed to provide information in support of evaluation of the ship's performance, and the structural regulations under which it was designed.

The project was in two phases, the first being identification of quality data and analysis procedure development, and the second, reduction of the bulk of the data.

The data analyzed consisted of strains measured in the bow of the ship, and the resulting analysis derived ice loads and pressures under various ship and ice conditions.

It is considered that the data collected, when combined with other technology in the field, has contributed to an understanding of the structural response of the vessel in ice and identified areas for future improvement.

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1. INTRODUCTION

The MV ARCTIC is the first Arctic Class 2 bulk carrier to be designed and built in accordance with CASPPR. Since its delivery in 1978, it has been operating to and from Arctic ports, and fitted with a computerized data acquisition system which enabled the collection of valuable data during three Arctic operating seasons from 1979 through 1981. This data has been documented and summarized in a Master Data Package which represents a comprehensive record of four dedicated trials and several Arctic voyages.

The overall objectives of the program, relevant to this study, are outlined in following:

(1) To evaluate the structural strength standards and other design criteria assumed to be necessary in the Arctic Shipping Pollution Prevention Regulations, for a vessel of Class 2, and to offer a quantitative and qualitative appraisal of these standards for other classes of icebreaking cargo vessels envisaged by these Regulations. This is the main concern of the present study.

(2) To evaluate the restraints on seasonal operational periods and zones currently established in the Regulations for a vessel of Arctic Class 2.

(3) To provide an instructional base upon which the expertise of ice navigation and commercial ship operation in Arctic waters may be further developed and dispensed.

To achieve the overall objective of the program a two phase approach was followed. The objective of Phase I was to establish the quality and quantity of useful data; develop methods and procedures for reducing and analyzing the data; and determine the most suitable presentation for best end use of the results.

Phase II of the study was devoted to the systematic data reduction and analysis of the bulk of the data in various performance categories. The data was used to determine the following for each performance category:

- the total ice load and pressure distributions over the instrumented sections of the ship.
- the ice failure characteristics.
- critical occurrences involving structural yielding or failure.

In addition to the above requirements, the results were used to evaluate the provisions of Schedule F of CASPPR.

An evaluation of the MV ARCTIC instrumentation system and data acquisition strategies has also been performed and will be most useful for future instrumentation programs.

2. DATA REDUCTION AND ANALYSIS

2.1 Data Categories

Data was analyzed under the following ship/ice performance categories on the basis of our perception of critical factors influencing the structural response of the MV ARCTIC.

General Category

ITEM	PRIORITY
Dedicated Testing	1
Transiting	1

Primary Category

Ramming in ridges	1
Thick MY floe impact in 10/10 cover or less	1
Continuous ahead icebreaking in level first year ice	2
First year floe impact in 10/10 cover ahead	3
Turning in level ice	4
Open water	1

Secondary Category

Ice conditions fully recorded and documented	1
Ice cover - observed good quality	2
Ice cover, snow covered poor observation decayed ice	3
Open water	4

Tertiary Category

Loaded condition, level trim, bubbler off	1
Ballast, bubbler off	2
Bubbler on	3

2.2 Data Reduction System

The data reduction and analysis system consisted of a Perkin-Elmer 9 track tape drive controlled by an APPLE IIe computer which transmitted the data to the HP9816 computer. The latter performs real time processing and selectively stores the data on a high capacity Winchester disc drive, as well as its own two micro disc drives. The output devices are supplemented with an HP7470A graphics plotter as well as an Epson dot matrix printer. This system provided an excellent compromise of friendly, low cost micro computer environment, as well as reasonable efficiency in handling large volumes of data.

2.3 Summary of Data Reduced

A total of 73.8 tape hours were scanned and reduced during this study on all performance categories. Breakdown by category is given in Table 1.

The selection of tapes was determined with due consideration of availability of quality data, i.e. where ice thickness, condition, ship velocity and test duration were generally available; strain gauge sampling rates of 1 Hz or faster; high stress/strain occurrences were in the documentation; and operation in the recording mode only.

During Phase I of the study, the necessary zero corrections of the signals were performed to compensate for drifting. All conversion and correction factors, channel/strain gauge numbers and locations, and the methods of data reduction and analysis were checked and verified. As a result, and after checks and comparisons with available data from other icebreaking ships, it was possible to conclude that the present data base was reasonably valid.

TABLE 1.

SUMMARY OF TAPES SCANNED AND REDUCED

CATEGORY	TOTAL DURATION OF RECORDS, HOURS	NUMBER OF TAPES		
		TOTAL	DEDICATED TRIALS	ARCTIC VOYAGES
Ramming	17.65	15	7	8
Continuous New Ice with Multi-Year Floes	18.50	12	2	10
Continuous New Ice	18.75	14	9	5
Broken Ice	9.42	6	1	5
Turning in New Ice	4.57	11	11	-
Open Water	4.67	2	-	2
Miscellaneous	0.15	1	-	1
TOTAL	73.80	61	30	31

3. ICE LOADS AND PRESSURES

The ice load was calculated from strain data measured in the area bounded by Frames 179 to 189 and Stringers 3 to 6, containing a total of 28 frame gauges in a nearly regular pattern. An algorithm was developed in [1] to calculate the total load from peak mode data. Load was calculated when peak strain $\geq$ 100 $\mu\varepsilon$ (i.e. stress $\geq$ 20 MPa); and strains are non-negative.

Ice pressure was calculated using the measured ice load divided by the mean area of imprint (1.5m^2) and also from a plate with four strain gauges extending over one half frame spacing and one stringer spacing, as shown in Figure 1. The former method was deemed the more accurate.

For each ice category, the calculated loads were plotted against the measured ship velocity and ice thickness.

No clear trends were observed between the ice load and ship speed or ice thickness. Statistical analysis allowed the following observations:

- continuous transit in level ice conditions results in the least ice loads for any probability level. The maximum ice pressure appears to be of the order of 5 MPa.

- the severity ranking, made at the 0.98 probability level, shows that the performance categories may be ranked as follows:

1.	Multi-year floes	: 6.1 MPa (2.4 x level ice)
2.	Broken channel	: 5.0 MPa (2.0 x level ice)
3.	Ramming	: 4.1 MPa (1.6 x level ice)
4.	Turning in Level Ice	: 3.4 MPa (1.4 x level ice)
5.	Level Ice	: 2.5 MPa (1.0 x level ice)

- the most severe performance category is that associated with multi-year floe impacts.

- the approximate frequency of impacts for the various performance categories was:

1.	Multi-year floes	28 impacts/hour
2.	Broken channel	16 impacts/hour
3.	Ramming	35 impacts/hour
4.	Turning in level ice	351 impacts/hour
5.	Continuous level ice	74 impacts/hour

The highest frequencies were associated with continuous operations in level ice conditions. When the ship was turning the frequency increased dramatically.

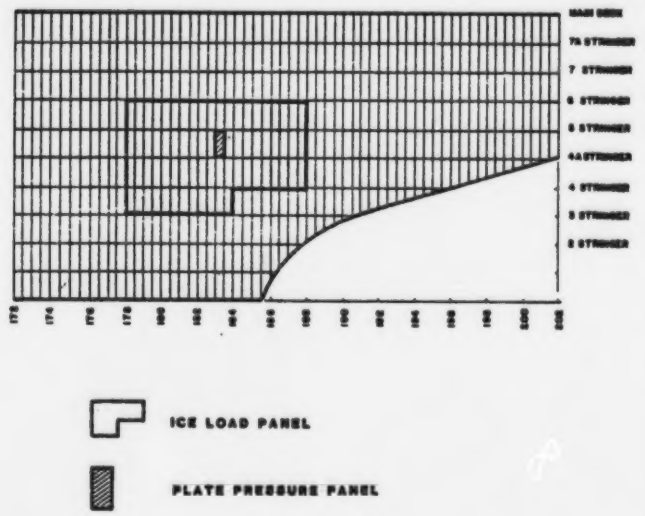
- The data was plotted using two quite different equations for the distribution of extreme values. It was shown that the value of extreme pressure extrapolated by such plots varies considerably with the type of plot selected, but the quantity of data available was insufficient to determine the form of extreme distribution to be used.

- The ramming operation is probably not best expressed in the present analysis because of the location of the ice load panel.

Ice pressures measured on the plate pressure panel were lower than pressures estimated from the load panel, due perhaps to the lack of an experimental calibration and the effect of ice bridging. Furthermore, local ice failure tends to be insensitive to the global mechanism of failure of the ice cover. Hence, the scatter of data may be attributed to the local variability of ice characteristics.

FIGURE 1

LOCATIONS of ICE LOAD/PRESSURE PANELS



4. HULL STRAINS

Information on strain rate and duration was derived from gauges sampled at high frequency (100 Hz and 500 Hz).

The three parameters used to study the results from the high rate gauges were duration, rate and peak strain values.

Two types of presentation were made:

- Comparison of actual data showing the peak mode strain record and corresponding real mode signal.

- Graphical presentation for all performance categories of:

  - strain rate versus peak strain
  - strain rate versus duration of impact signal
  - strain rate histogram.

  for both plate as well as frame gauges.

Figure 2 summarizes the data.

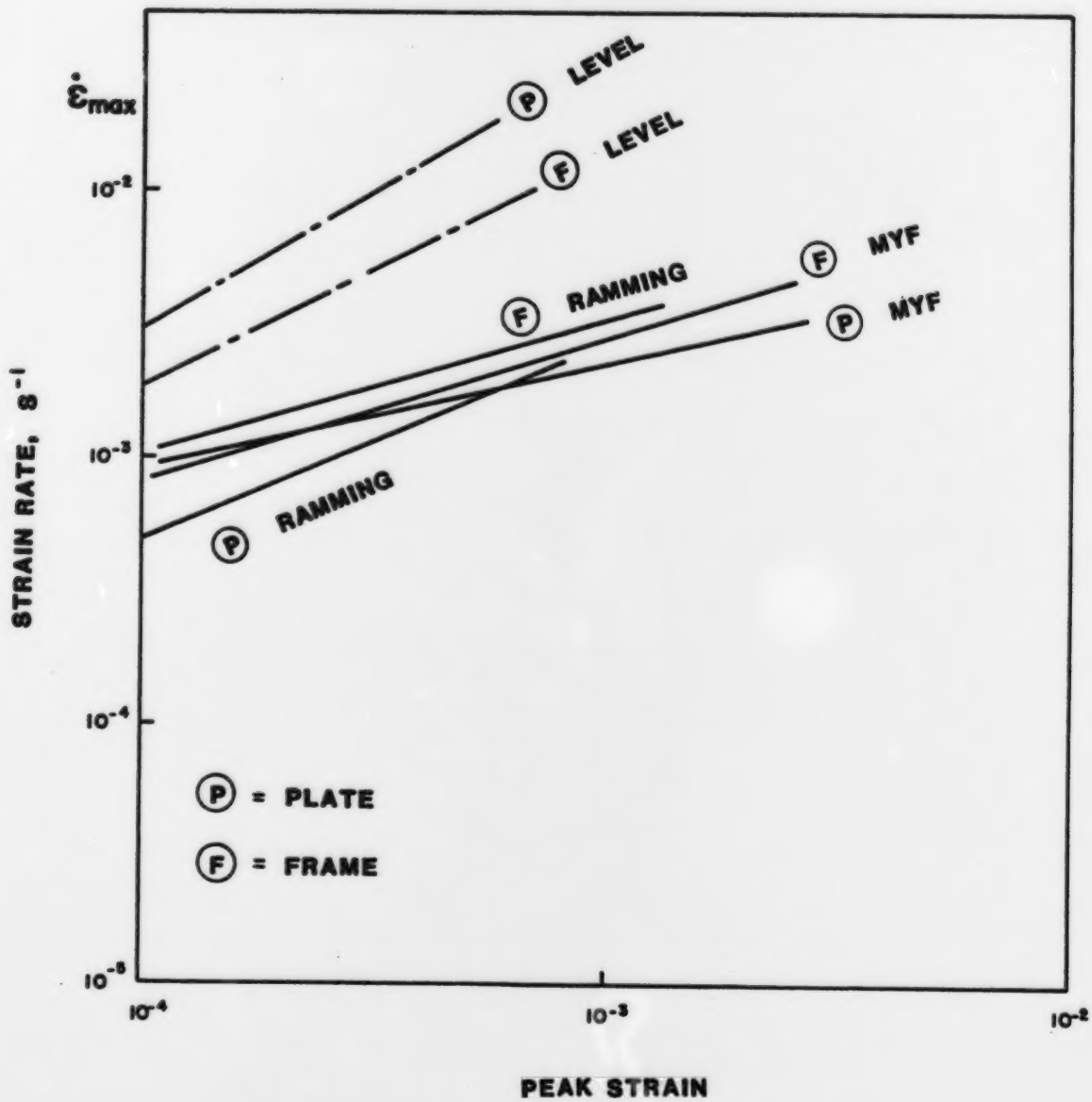
The largest strain rates were observed during continuous progress in level ice where bending failure of ice was predominant. Strain rates associated with ramming and multi-year floe impact are of the same magnitude. Crushing failure of ice may predominate.

While frames experience slightly higher limits of strain rate than plates in ramming and multi-year floe impact, this tendency is reversed during continuous progress in level ice due perhaps to the "bridging" effect in which plates "avoid" the main impact in a large area.

Maximum strain rates appear to be linearly proportional to peak strains. This suggests a basic relationship associated with the ship/ice interaction phenomenon. The maximum strain rate recorded during the MV ARCTIC data collection program is of the order of $10^{-2} s^{-1}$.

FIGURE 2

UPPER LIMIT of DATA on STRAIN RATE



5. DISTRIBUTION OF STRESS AND STRAIN

The location and concentration of loading on the bow under various ship/ice interactions was determined from the statistical data at each gauge location. The data was taken from histograms for each gauge at that value below which 90% of the data fell, and was considered to be a realistic maximum value for comparative purposes.

Peak stress profiles along different waterline levels were plotted as well as Iso-stress contours constructed using the profiles and exercising some engineering judgement. Examples are shown in Figure 3.

This unique presentation took advantage of the large number of gauges and displayed logical trends that are supportable by the observed physics of the ship/ice interaction in each category. The following remarks may be made:

- Peak frame stresses were approximately equal in the various modes of operation, and did not exceed 140 MPa or about 60% yield. Whereas peak plate stresses were somewhat higher than frame stresses.

- The location and distribution of peak stress in plates and frames are not identical, indicating differences in interaction response and stimuli in the form of changing ice/ship interaction phenomena. The frames react to larger area loads, and the phenomenon of "bridging" in these larger areas results in lower responses in the plates.

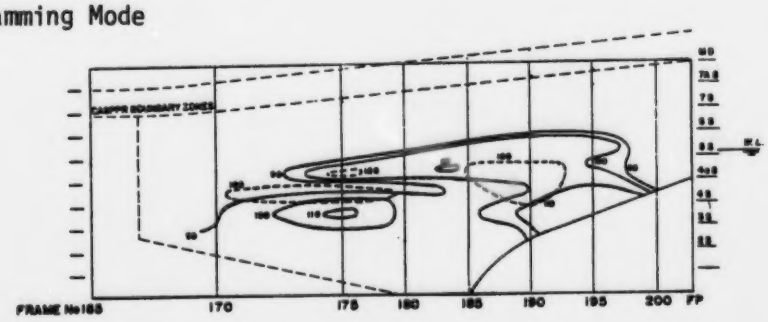
- The CASPPR bow zone of ice belt strengthening appears to adequately envelope potential high stress areas.

- Peak loads occur at or somewhat forward of Frame 185. The selection of Area 1 (Bulkhead 178 - Bulkhead 188) as the principal "panel" for locating gauges has been justified while extension of the array to the stem would have been instructive.

FIGURE 3

HULL STRESS CONTOURS

a) Ramming Mode

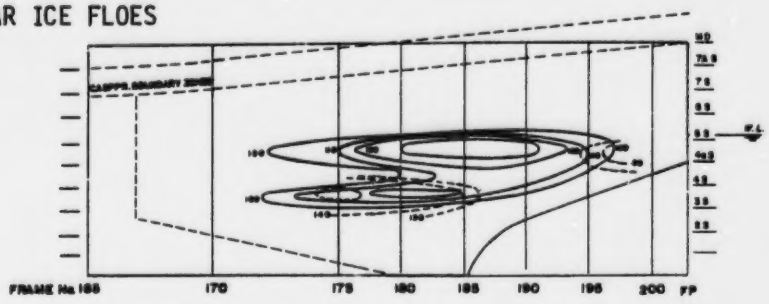


W REPRESENTS PEAK OF 90% OF DATA

FIGURE 3

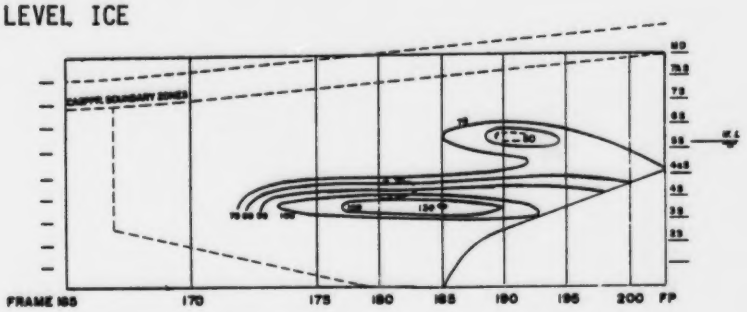
HULL STRESS CONTOURS (con't.)

b) MULTI-YEAR ICE FLOES



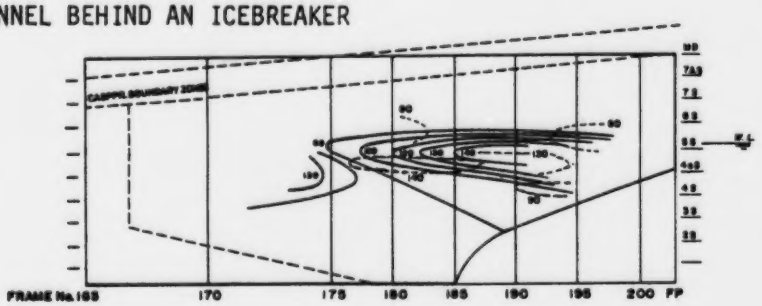
* REPRESENTS PEAK OF 90% OF DATA

c) CONTINUOUS LEVEL ICE



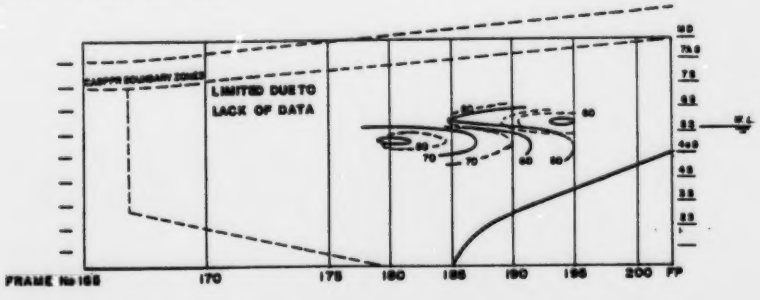
* REPRESENTS PEAK OF 90% OF DATA

d) BROKEN CHANNEL BEHIND AN ICEBREAKER



* REPRESENTS PEAK OF 90% OF DATA

e) DURING TURNING IN LEVEL ICE



* REPRESENTS PEAK OF 90% OF DATA

6. CASES OF STRUCTURAL FAILURE

Some cases of structural failure were examined to assess the conditions under which yielding or failure occurred.

A summary of the locations of impacts where yielding occurred is shown in Figure 4.

In Case 2, the recorded strain data did not correspond to the reported damage area, and indicated that damage occurred earlier, probably at a time when data was not being recorded. The material was strain hardened and even high strains of the order of 1700 micro strain did not result in an offset.

In Case 3, a multi-year floe impact, it was shown that the contact with ice spread over two major contact locations. The ship was in load condition and was progressing in continuous mode in level ice at six knots when she hit a multi-year floe. it was projected that maximum ice load in the aft location was 14.45 MN (1473 tonnes). At the foremost location, the maximum strain was higher and the load was estimated to be of the order of 19 MN.

For another case (Case 4) associated with multi-year floe encounter at 7 knots estimated ice loads/pressures were:

- 17 MN (1730 tonnes) = Frame 180/181 at height waterline
- 23 MN (2340 tonnes) = Frame 183 at height waterline
- 3.7-5.9 MPa plate pressure = Frame 181-181½ & Stringer 4-4A

FIGURE 4(a)

AREAS OF ICE ACTION ON THE BOW STRUCTURE DURING OBSERVED FAILURE CASES

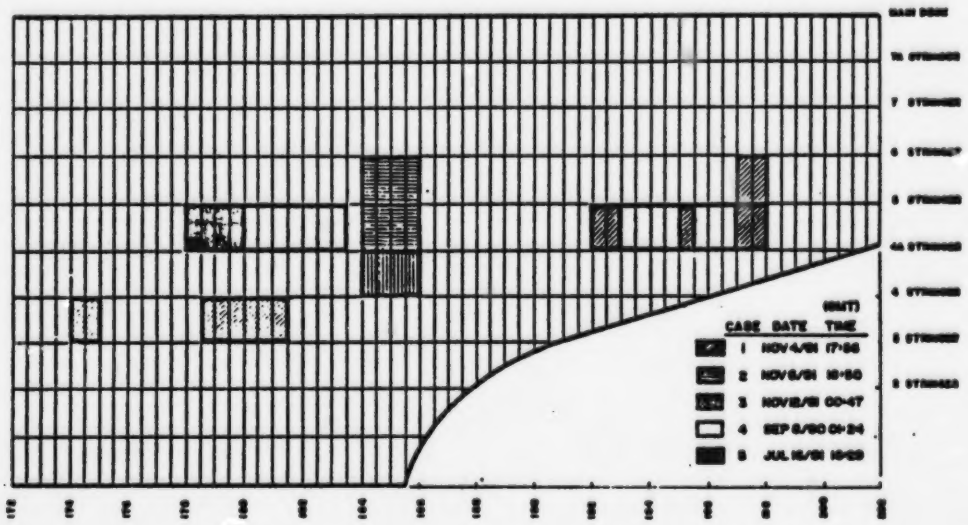
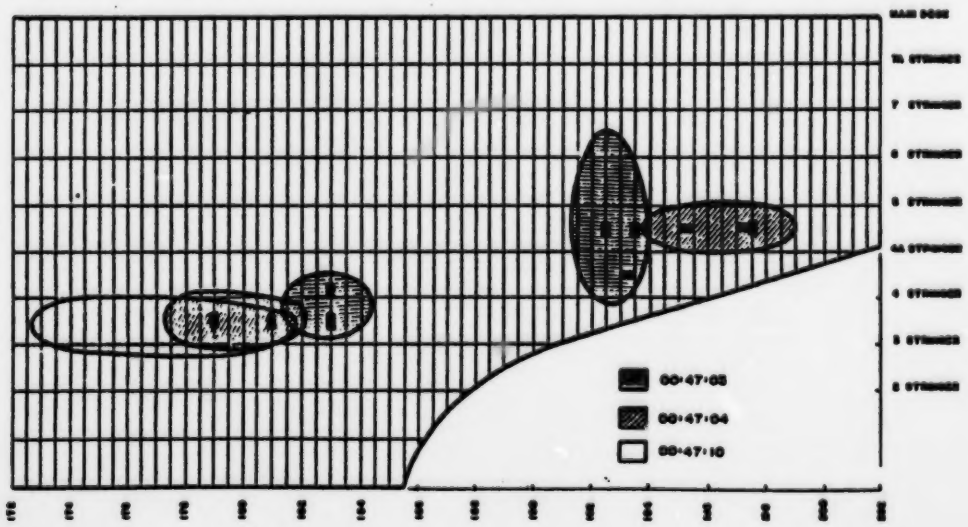


FIGURE 4(b)

RECONSTRUCTED IMPACT CASE WITH A MULTI YEAR FLOE

(Case 3)



7. EVALUATION OF CASPPR RULES

MV ARCTIC was designed to Class 2 requirements under Schedule F of CASPPR which specify that the shell and main frames must be able to withstand the 4.14 MPa (600 psi) pressure without yield. The comparison of plate panel pressures and loads and those of the load panel suggest that larger loads allow local shedding by the plates due to ice bridging and that the actual pressure in the impact is non uniform, being quite high over a local area.

The extent of uniform loading assumed in the design of frames in CASPPR is 800 mm vertically. In the absence of other information, this height seems reasonable, although the assumption of uniformity is not reasonable while the 4.14 MPa (600 psi) specified in Table 2 of CASPPR is intended to be an ice load which does not result in yield, (qualified by an estimated +50% accuracy (see Ref. [1]). The design load for stringers taken from Table 3 of Schedule F is 0.81 MPa, a value clearly requiring adjustment both in terms of pressure and assumed area of loading. Measured peak pressures of over 8.2 MPa were recorded.

The shell plating thickness as specified in CASPPR based on the development of three plastic hinges in a fixed-fixed beam may be assumed to be subject to a uniform load, and a safety factor of 1.5 (after Nawwar [2]), or no safety factor in yield is a simply supported plate panel. A full plastic hinge collapse requires loading somewhat beyond initial yield and can be shown that 1.8 σ_y is the level of stress for this collapse mechanism. Thus the data was plotted against σ_y and 1.8 σ_y.

Extreme value statistics for all strains occurring in plate and frame gauges exhibiting the greatest responses were used to assess the suitability of these CASPPR requirements. Figures 5 (a) and (b) are the extreme stress distributions for plates and frames for different performance categories.

The results showed the risk of plate yielding varies with location, and the likelihood of plate failure appears to be greater in multi-year ice and broken ice than in other conditions.

The risk of frame yielding varies widely with location and ice interaction condition. However, the likelihood of frame failure appears to be high during ramming as well as in multi-year ice and broken ice conditions.

In any two minute interval, there is a 3% chance that stress level at the location of the gauge will exceed 50% yield.

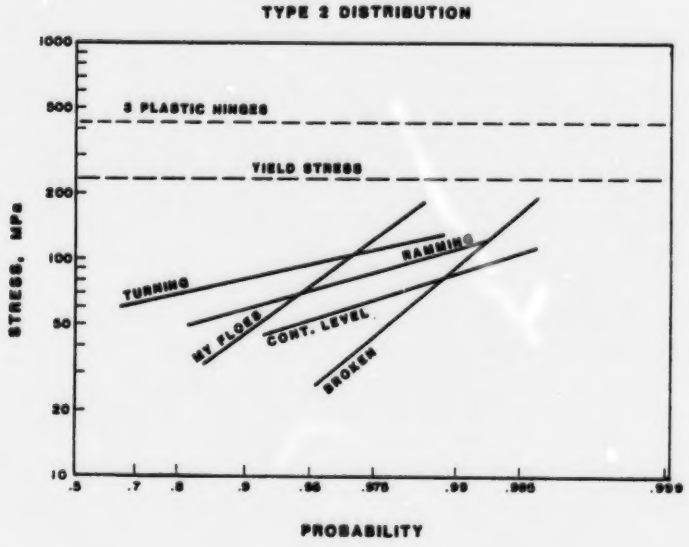
The conclusion we draw from this is that the plating does not appear to have adequate margin against failure, and that the specification of shell thickness results in a high probability of permanent set in the plate. The recorded data implies that the frames are at much lower risk than the plating, and that indeed the strength level specified in CASPPR may well be acceptable.

FIGURE 5

a)

EXTREME PLATE STRESS DISTRIBUTION

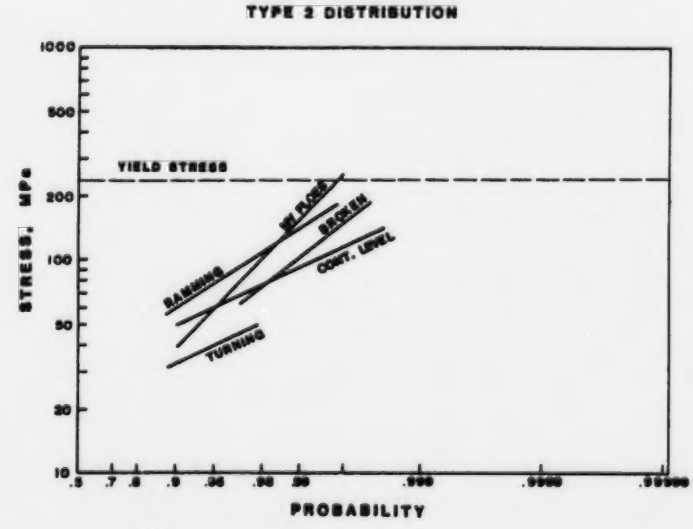
(ENVELOPE OF ALL PLATE DISTRIBUTIONS)



b)

EXTREME FRAME STRESS DISTRIBUTION

(Envelope of all frame data)



8. EVALUATION OF INSTRUMENTATION SYSTEM

It is now generally recognized that the data acquisition system fitted onboard MV ARCTIC was deficient in a number of areas including design philosophy, equipment and component selection and installation. Our purpose was to identify those aspects of the system that directly affected the quality and quantity of the data and to make recommendations for future systems.

The overall location of the instrumented area was good, being the area subject to the most ice impact activity. Gauges near the stem could have provided useful data on peak ramming stresses.

While the placement of gauges on frames in Area 1 formed a fairly regular grid, the grid size was too large for the expected impact areas reducing the quality of the data.

Regular grid of reliable (preferably duplicated) gauges is necessary, with the gauges placed such that there is a unique loading case causing a measured response. In general, shear difference, compression, etc. are preferable to bending gauges as the latter can result from a number of loading conditions.

The rationale for the placement of gauges on this vessel was not understood.

No useful purpose was served by fitting single isolated 'monitoring' gauges on the port side as there was no unique solution to the load causing the measured response.

Gauges should be placed to accommodate expected impacts from other modes of operation other than level icebreaking.

The finite element model must be structured and meshed to provide output at the gauge locations.

Gauge calibration using a finite element model can only be made if the latter is meshed to provide output at the gauge locations.

The actual documentation of the voyages was generally poor, partly because the high level of system maintenance prevented the operator from making appropriate records of ship and environmental conditions.

Standards or guidelines for tape identification, logging, tape replacement, etc. must be set and, the splitting of responsibility for the data collection program among several organizations must be avoided.

The gauges on the port side and those above the waterline provided little useful information. More accurate loads and pressures could have been determined if these same channels were used for a finer measurement grid in the vicinity of the load and pressure panels.

Based on our experience with the data analysis of the MV ARCTIC in the current and other projects the following improvements are suggested.

- more accurate records of file times and tape contents,
- better documentation of filter channels,
- better records of gauge placement and replacement,
- recording the location of the gauge being scanned in the header.
- standardization of file lengths (recording times).
- a document such as the Master Data Package should be more organized for search convenience and speed.

9. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the data reduced and analyzed in the present study the following conclusions were drawn:

- The data collected on MV ARCTIC in 1979-81 had contributed to the knowledge of the performance of an icebreaking merchant vessel in the Arctic, and added to the understanding of the ship/ice interaction. In particular, analysis of the structural data reinforces some of the assumptions and findings concerning ship/ice interaction which have been arrived at in the studies to update CASPPR.

- The environmental conditions recorded in dedicated tests were not generally sufficiently well documented or varied enough to permit deterministic relationships to be developed. In addition, the limitations caused by the limited location of gauges and the peak mode of system operation were such that only statistical data was of value.

- The structural response under continuous first year level icebreaking was somewhat lower than in other icebreaking modes. The data also showed that the ice conditions did not contribute greatly to the level of loading on the hull.

- Ranking of the pressures on the hull using level ice as a reference and listing the 98% probable ice pressure over 1.5 square meters of contact with ice gave:

  1. Multi-year floes : 6.1 MPa (2.4 x level ice)
  2. Broken channel : 5.0 MPa (2.0 x level ice)
  3. Ramming : 4.1 MPa (1.6 x level ice)
  4. Turning in Level Ice : 3.4 MPa (1.4 x level ice)
  5. Level ice (continuous) : 2.5 MPa (1.0 x level ice)

  This data suggests that strength regulations based on level icebreaking performance are not appropriate. It should be noted that the absolute values above are subject to a ±50% error spread.

- The frequency of impacts were logical and appeared to match the nature of the icebreaking process in each case:

  1. Multi-year floes : 28 impacts/hour
  2. Broken channel : 16 impacts/hour
  3. Ramming : 35 impacts/hour
  4. Turning in level ice : 351 impacts/hour
  5. Continuous level ice : 74 impacts/hour

- Structural yielding resulted from ice loads as high as 23 MN (2340 tonnes) acting on 1.5 square meters (an average ice

pressure of 15 MPa (2,200 psi) and were assosciated with operations among multi-year floes.

- Strain rates on the shell plating were greater than those on frames and the maximum strain rate was of the order of 10^{-2} s^{-1}.

- The main instrumented panel was well located, being in the area that received the most and largest loads.

- Hull stress contours indicated that 90% of the time stresses remained within 60% of the yield strength of the steel.

- The CASPPR bow zone of ice belt strengthening adequately enveloped potential high stress areas.

- Based on measured stresses and using extreme value statistics CASPPR requirements for plates indicated a high probability of yielding. During 48 hours of transit in multi-year ice per voyage, the hull experienced 11 to 15 plate yield incidents (minor dents) and 1 to 7 plastic hinge incidents (medium dents). The range of expectations represented different probability distributions. This evidence can be corroborated from other sources.

- CASPPR requirements for frames indicated a greater safety margin - than plates. For twenty hours of ramming (more critical to frames) the frames were likely to experience 1 to 2 yield events, but three hinge plastic collapse should not be expected before 70 to 80 hours of ramming mode operations.

- The data acquisition system fitted onboard the MV ARCTIC was deficient in a number of areas including design philosophy, equipment and component selection, and installation. The sensor failure rate was high and the peak mode recording was not compatible with a comprehensive analysis of structural response.

- The overall location of the instrumented area was good. However, the distribution of gauges within the panel and sparcity of gauges in other critical areas such as the stem, offset some of the advantages.

- The documentation of tapes (either on-tape or off-tape) created several problems in data reduction and interpretation.

- The gauges placed on the port side were of no value. A single isolated gauge could not provide adequate information, particularly in view of the local nature of the loads.

Recommendations

General

- Instrumentation of the hull should be considered early enough in the design stage to be integrated in order to alleviate problems during installation, improve reliability and extend its service life.

- High levels of loads and pressures can be expected during turning and maneuvering in level ice. This phenomenon should be further investigated aimed at assessing what limitations should be imposed on turning maneuvers in ice.

- The instrumentation and data acquisition system must be designed with objectives.

- The MV ARCTIC has been the subject of several studies by several organizations. All these efforts should be the subject of a separate investigation which consolidates the information, identifies areas of agreement or contradiction, and renders major conclusions.

Designers

- The distribution of load over the bow area indicates that heaviest loading occurs in the region of the shoulder which should be 'eased' with shallower lines if feasible.

- Plate panels respond most severely to smaller loads. For larger loads the phenomenon of 'bridging' appears to alleviate stress on plate panels, shedding the load to frames. However, since the loading from ice impact can be quite local, we recommend that 'bridging' be ignored in the design of shell plating, and certainly not used to justify acceptance of a plate thickness that would have a high probability of failure if bridging were not assumed.

- The natural period of a plate panel should be calculated and compared with the period of loading associated with the impacts measured. If they are close, a check on loading with a dynamic amplification factor on the load may be necessary.

- The design of local structure should be based on application of realistic ice pressures over meaningful areas of the bow in accordance with a pressure versus area relationship.

- The formula for thickness of plate in the current regulations should be considered only as a lower bound, with the overriding criterion being that of non yield as specified in paragraph 5 of the schedule.

- Instrumentation of the hull for purposes of monitoring ice loads and response should be considered as an integral part of the design process.

Operators

- Loads on the bow of the vessel in ice are not strongly related to vessel speed because capability of the vessel in thicker ice limits the speed attainable.

- The least ice loads/pressures on the hull may be expected during operation in continuous cover of level ice. However, the presence of multi-year floes can be extremely dangerous particularly if the continuous ice is thin, allowing the ship to proceed at higher speeds.

- Turning and maneuvering, particularly ramming maneuvers, in level, continuous or broken ice increases the probability of damage.

- A warning system based on isolated sensors is of little value. Operators should not rely entirely on such systems and should not preclude the possibility of local damage even when such a system indicates no danger.

- Data collection on ice characteristics and conditions of interaction should be documented on all possible occasions.

10. REFERENCES

[1] Glen, I., Nawwar, A., "MV ARCTIC Structural Performance", TP 5682E, ACL Interim Report 1500C, submitted to Transportation Development Centre, October 1984.

[2] "A Rationale Basis for the Selection of Ice Strengthening Criteria for Ships", Ships Structures Committee SSC 309.